RHS **Ralston Hydrologic Services, Inc.**

GROUND WATER CONSULTING AND EDUCATION

1122 East B Street, Moscow, ID USA 83843

Voice and FAX 208-883-0533, E-mail ralston@moscow.com

MEMORANDUM

To: Cary Foulk PG -- MWH Americas
From: Dale Ralston PhD PE PG -- Ralston Hydrologic Services
Subject: Ground-Water Flow Characteristics at Monsanto Mine Sites
Date: January 29, 2008

The purpose of this memo is to provide you with my analysis of ground-water flow systems in consolidated rock formations at the Ballard, Henry and Enoch Valley Mines in light of ongoing studies at the Blackfoot Bridge mine site and my hydrogeologic experience in the southeastern Idaho phosphate area. Recommendations are provided relative to the location of new monitor wells. Ground-water flow systems in unconsolidated deposits are not addressed in this memo because of the planned investigation using the direct push program in 2008. The following topics are included in this memo: 1) hydrogeologic controls for ground-water flow; 2) insight gained from investigation of the Blackfoot Bridge mine site; 3) flow system analysis at the Ballard Mine; 4) flow system analysis at the Henry Mine; and 5) flow system analysis at the Enoch Valley mine. Locations of the four mine sites are shown on Figure 1. The reader is referred to the MWH report for geologic maps and cross sections for the Ballard, Henry and Enoch Valley mine sites.

Hydrogeologic Controls for Ground-Water Flow

The Darcy equation is the primary tool for predicting ground-water flow. The specific discharge (discharge divided by cross-sectional area) is equal to the product of the hydraulic gradient and hydraulic conductivity. Application of the equation is simple in hydrogeologic environments that can be considered as homogeneous and isotropic. Authors in the 1960's developed concepts of local, intermediate and regional ground-water flow systems based on solving the Darcy equation in a homogeneous, isotropic system with simple boundary conditions. Authors in following decades developed progressively more complex representations of ground-water flow systems using both analytical and numerical models. The primary constraint on application of these models to specific areas is knowledge of the three dimensional distribution of hydraulic conductivity on the scale of interest to the problem at hand.

Formulation of a hydrogeologic conceptual model (general description of the three dimensional distribution of hydraulic conductivity) is based on knowledge of the site geologic framework. This statement is true whether the problem to be addressed is a large scale basalt aquifer, a small scale unconsolidated valley fill aquifer or a complex sequence of aquifers housed within structurally deformed, consolidated sedimentary rock. Geologic information in the form of maps and cross sections is used to develop a threedimension geologic conceptual model. Knowledge of the general hydraulic properties (three-dimensional hydraulic conductivity distribution) of each of the subsurface units is used to transform the subsurface geologic model to a subsurface hydrogeologic model. Information from wells is used to refine the hydrogeologic conceptual model to the level of detail necessary for the problem at hand. This information includes the three-dimensional distribution of hydraulic head, and in some situations, the two or three dimensional distribution of hydraulic conductivity.

A general hydrogeologic understanding of the "phosphate sequence" of geologic units has been developed over a number of decades of research and investigations in southeastern Idaho. The "phosphate sequence" includes the geologic units immediately above and below the Phosphoria Formation which is the target for development of phosphate mines. Much of the research was conducted by graduate students at the University of Idaho under my direction. Studies conducted since completion of the university research has resulted in only limited adjustments to the general understanding of formational properties.

- The Thaynes and Dinwoody Formations contain zones of relatively high hydraulic conductivity. These formations are stratigraphically higher than the Phosphoria Formation and often host ground-water flow systems.
- The Phosphoria Formation has a lower bulk hydraulic conductivity than any of the other formations in the "phosphate sequence". The Rex Chert Member has sufficient fracturing in various locales to be an important water-bearing unit. The Meade Peak Member has very low hydraulic conductivity at the majority of sites.
- The Wells Formation contains zones of high hydraulic conductivity and has the highest bulk hydraulic conductivity of formations within the "phosphate sequence".
- The Phosphoria Formation often separates shallow ground-water systems in the Thaynes and Dinwoody Formations from deeper ground-water flow systems in the underlying Wells Formation.

Ground-water flow within each of the above described units is controlled by bedding features as well as structural setting. As a general rule, with-bedding hydraulic conductivity is much higher (by a factor of 10 or more) than cross-bedding hydraulic conductivity. This anisotropic characteristic occurs on small scale (in terms of feet) and large scale (in terms of hundreds or thousands of feet). Folding of the consolidated rock sequence causes the bedding being oriented at an angle rather than horizontal. Thus, the strike and dip of formations are important relative to controlling the pattern of ground-water flow. The axis of a fold (syncline or anticline) can be an area of more intense fracturing and thus higher hydraulic conductivity. This is particularly important for brittle rocks such as chert.

Faults can play a major role in controlling ground-water flow. A fault can impact the three-dimensional distribution of hydraulic conductivity in at least three ways. First, the fault can offset higher hydraulic conductivity zones and thus cause a discontinuity in a preferential flow path. The amount of offset on the fault is important because it controls the degree of hydraulic disconnection of preferential flow paths along bedding. Second, movement along a fault results in the creation of ground-up rock (gouge) that generally has lower hydraulic conductivity than the original rock. The fault with significant offset (say 100 feet) can act as a barrier to lateral ground-water flow both because of the offset of higher hydraulic conductivity bedding features and because of gouge material along the movement plane. Third, zones of higher hydraulic conductivity often are created parallel to the fault because of intense folding on one or both sides. This is particularly the case where the fault cuts through brittle rock.

University research efforts and more recent mine site studies have resulted in the identification of ground-water flow systems that are typically associated with a given set of geologic conditions. However, each mine site has a unique structural setting that makes site-specific studies necessary. Knowledge of site-specific structural features is a major factor in gaining an understanding of ground-water flow systems at any mine site.

Blackfoot Bridge Site

The Blackfoot Bridge site is discussed as an example of characterization of ground-water flow systems and as a base to understand the three closed Monsanto mines, particularly the Ballard Mine. Test wells have been constructed (Figure 2) and data collection has included ground-water levels, an aquifer test and ground-water quality. The hydraulic connection with a nearby surface water feature has been investigated both in terms of stream gains and/or losses and in terms of water quality. A detailed level of geologic knowledge has been gained from both surface mapping and information from drill holes.

The geologic map of the northern portion of the Blackfoot Bridge site (Figure 3) shows a fabric of approximately north-south structural features with the largest of these being the Aspen Range Fault. Smaller north-northwestern faults are shown along or near the outcrop of the Phosphoria Formation east of the Aspen Range Fault. The geologic map also shows three approximate east-west faults in the northern portion of the site. The formations dip to the east and the north-south normal faults that are located east of well PW-1 each have about 100 feet of offset.

Water-level data are available for site wells ranging from one measurement (fall 2007) in some of the wells (MW-17W, MW-18Da and MW-18Db) to up to seven measurements (fall 2005 through fall of 2007). Well designations include the formation target for each well: Wells Formation (W designation on well number), Dinwoody Formation (D), alluvium (A) and Rex Chert (R). In addition, water-levels are available for nine of the wells completed in the Wells Formation from the aquifer test program.

Well MW-4W is of particular importance as it is completed within the Wells Formation and represents the hydraulic head and temporal variations of the ground water upwelling along the Aspen Range fault from a postulated regional ground-water flow system. The range in water-level elevations (0.64 feet) is small with a mean water-level elevation of 6,217 feet. For reference, the approximate elevation of Woodall Spring, located about 0.5 miles south of the well, is 6,226 feet (based on a digital topographic map). The small annual fluctuation fits with the location of the well within the discharge area of a regional ground-water flow system.

Well MW-14W is located north of MW-4W near the Blackfoot River and has a water-level considerably above land surface. The average of the pressure readings for well MW-14W is equivalent to a water-level elevation of about 6,195 feet. The lower water-level elevation for well MW-14W (relative to MW-4W) may be related to the location of the well near a discharge area. Springs and seeps from the regional ground-water system (based on water quality parameters) discharge into the Blackfoot River at elevations in the approximate range of 6,140 to 6,150 feet.

A group of wells (PW-1W, OW-1W, OW-2W, 2006-35V1 and MW-8W) are completed within the Wells Formation and have water-level elevations in the range of 6,177 to 6,191 feet. Hydrographs for the first four wells are similar to well MW-4A and have small annual fluctuations. Well MW-8W has slightly greater annual water level changes. Well PW-1W was pumped during the aquifer test and drawdown was measured on the other four wells in this group. No clear direction of ground-water flow can be determined from this group of wells even though they have been shown to be hydraulically connected.

Four nearby wells, completed within the Wells Formation, have somewhat lower water-level elevations and did not show drawdown during the aquifer test. These wells (2006-37V1, 2006-37V2, 2006-38V1 and 2006-33V1) have ground-water levels that are mostly lower than the first group of wells with only small seasonal water-level changes. These wells are located east of the mapped north-south faults. Again, no clear direction of ground-water flow can be determined from these wells.

There are at least two alternative interpretations of the hydrogeologic data for the Blackfoot Bridge site. The first approach is to prepare a water-level contour map using all of the well data described above, regardless of their hydraulic interconnection. This results in the water-level contours shown on Figure 3. The water-level contour lines are oriented approximately north-south. In an isotropic system, this indicates a general ground-water flow direction approximately from west to east.

A second possible interpretation of the Blackfoot Bridge area is that the north-south and east-west faults act as semi-permeable barriers to ground-water flow. The faults form the boundaries for blocks of the Wells Formation that have limited hydraulic connection to the adjacent blocks. The results of the aquifer test support this conceptual model. The Blackfoot Bridge site has ongoing study that includes evaluation of which alternative conceptual models best represents the ground-water conditions at the site.

Ballard Mine Site

The Ballard Mine site is geologically more complex than the Blackfoot Bridge site with a large number of mapped and inferred structural features. A plan view geologic map prepared by MWH shows locations of mine features, seeps and springs and wells. Geologic cross sections prepared by MWH show mapped and inferred faults and folds. The north-south and east-west trending faults have estimated offsets ranging from tens of feet to hundreds of feet.

Based on my experience, I believe that the faults at the Ballard Mine site form the boundaries for blocks of the consolidated rock formations that have limited hydraulic connection to the adjacent blocks. The first evidence for this conceptual model is the faulted nature of the geologic setting of the mine as compared to the Blackfoot Bridge site. The second evidence is from temporal water-level data from wells completed in the Wells Formation.

Wells MMW001 and MMW002 (drilled to depths of 450 and 350 feet) were located east and west of pit MMP035. Given the east dip of the units, well MMW001 was completed stratigraphically higher within the Wells Formation than well MMW002. These two wells were replaced by wells MMW020 and MMW021 (depths of 408 to 250 feet) in 2007 because of well construction problems related to water sampling (turbidity). MWH cross section H-H' shows the locations of the new wells relative to site geology.

Water-level elevation data from hand measurements taken in wells MWW001 and MWW002 from 2004 to 2007 are presented in Figure 4. Observations relative to the hydrographs are presented below.

- The water-level elevation for well MMW001 (located east of pit MMP035) has a large range from a minimum elevation of 6,236 feet in May 2004 to a maximum elevation of 6,260 feet in July 2006. The hydrograph shows an apparent small peak in July 2005 from spring recharge and a much larger peak in July 2006 from spring recharge. The water content of the snow pack was higher in 2006 than in 2005. The water-level rise from the November 2005 reading to the May 2006 reading was about 18.4 feet. Limited information from a data logger installed in the well indicates that most of the water-level rise occurred in April 2006. The water-level declined about six feet from October 2006 to October 2007.
- The data for well MMW002 shows a smaller and delayed water-level rise associated with spring 2006 recharge event with a very gradual water-level recession to the last reading in August 2007. The total range of water-level elevation in well MMW002 was about 11.5 feet.

The water-level patterns shown on Figure 4 for the wells completed in the Wells Formation at the Ballard Mine site are unusual. The expected pattern would be a high water level in the spring followed by declining water levels over the summer and fall with a high water-level again the next spring. I believe that the water-level patterns at wells MMW001 and MMW002 represent annual recharge into a highly bounded system with the slow water-level decline (shown particularly in well MMW002), representing the leakage through the bounding faults.

Water-level elevation data are available for the Wells Formation from three wells at the Ballard Mine site for October 2007: MMW020 at 6,252 feet, MMW006 at 6,236 feet and MMW021 at 6,236 feet (see the MWH plan view map). Assuming a vertical gradient downward in the Wells Formation (consistent with the location of the mine in a recharge area), a portion of the water-level difference between MMW020 and the other two wells is in part because MMW020 is screened higher in the stratigraphic section. The inferred flow direction from the 2007 water-level data is to the southwest.

On a larger scale, the likely ground-water flow direction within the Wells Formation near the west side of the Ballard Mine is to the north-northwest. The logic for this conclusion is as follows. First, ground-water flow along strike (north-northwest or south-southeast) is likely to occur because flow in either of the other two directions (north-northeast or south-southwest) would be across bedding. Second, regional ground-water discharge occurs to the northwest near the Blackfoot Reservoir as identified by previous investigators.

The analysis of ground-water flow in the Wells Formation would benefit by the construction of an additional monitor well to the northwest of the mine-impacted area. A new monitor well completed in the Wells Formation in the general vicinity of well MMW017 (which is completed in the alluvium) would appear to satisfy this need.

The Dinwoody Formation is present at land surface south and east of the mine (see MWH plan view map). MWH cross sections H-H' and Q-Q' show that the Dinwoody Formation is present in a syncline between pits MMP035 and MMP036. Downward ground-water flow from the Dinwoody Formation to deeper units likely is limited by the underlying Phosphoria Formation. Ground-water flow to the north appears to be limited by the fault as shown on cross section Q-Q'. Also, the syncline appears to plunge to the south. Ground-water flow in the Dinwoody Formation along strike to the south is constrained in two ways. First, approximately east-west structures likely are present along the southern site of the mine. Second, the Dinwoody Formation outcrops at much higher elevation to the south. The hydraulic head in the Dinwoody Formation to the south likely is higher than in the mine area. Most likely, ground water from the center block of the Dinwoody Formation discharges into the alluvium near the southern margin of the area. The direct push program for investigation of the unconsolidated surface sediments, planned for 2008, can be used to investigate this potential pathway.

The Dinwoody Formation is depicted as underlying alluvium east of the mine site in MWH cross section S-S'. The dip of the consolidated rock is eastward in this area with the formation truncated on the east by the Slug Valley Fault. Given the configuration of the formation in this area, ground-water flow in this unit likely is along strike in a north-south direction. Ground-water flow to the north is unlikely based on outcrop configuration of the Wells Formation on Figure 4. Thus, the likely ground-water flow direction within the Dinwoody Formation in this area is to the south.

Well MMW018 was drilled into the alluvium along cross section S-S' and penetrated into the top of the Dinwoody Formation. A new monitor well constructed deeper into the Dinwoody Formation in the general vicinity of MMW018 would be valuable in the investigation of ground-water quality in the Dinwoody Formation. The specific location of the well should be selected based on water quality data in the alluvium obtained as part of the 2008 direct push program.

Henry Mine Site

The Henry Mine is geologically less complex than either the Ballard Mine or the Blackfoot Bridge mine site. Mine pits are constructed along the strike of the consolidated rock units with the Center Henry and South Henry workings located south of the Little Blackfoot River and the North Henry workings located north of the river (see the MWH plan view map). The formations dip to the east-northeast with the Phosphoria outcrop on the east side of the ridge. The Wells Formation outcrops on the top and west side of the ridge and the Dinwoody Formation outcrops east-northeast of the mine pits. The primary structural feature in the area is the Henry thrust fault located northeast of the mapped outcrop of the Dinwoody Formation in most areas. From south to north, MWH cross sections N-N', B-B' and P-P' show the configuration of the consolidated rock formations.

Ground-water flow in the consolidated rock formations is expected to follow the strike of the units (northwest – southeast). An east-west offset of the Phosphoria Formation forms the southern end of the Henry Mine. This tear fault likely is significant in limiting ground-water flow south along strike in this area. MWH cross section B-B' shows the configuration of the Henry thrust fault particularly relative to the Dinwoody Formation. There are no documented springs along the mapped trace of the Henry thrust fault although the lowest elevation of the feature near the Little Blackfoot River is covered by basalt.

The logical direction for ground-water flow in the Wells Formation at the Henry Mine is to the northwest along the strike of the unit. Two wells were installed in 2007 to provide information on this potential pathway. Well MMW011 is located immediately south of the Little Blackfoot River and well MMW023 is located in the North Henry Pit. The casing elevations for these two wells were not surveyed prior to the onset of winter. The water-level elevations in the two wells are believed to similar. I assume that the ground-water elevations for the two wells will show a small hydraulic gradient to the north-northwest. These two wells are located to document ground-water quality in the Wells Formation down-gradient from the mine-impacted areas. I do not believe that additional monitor wells completed in the Wells Formation are needed at the Henry Mine.

The logical direction for ground-water flow in the Dinwoody Formation is to the northwest along strike with a possible component to the east with potential discharge along the Henry thrust fault. One well (MMW022) has been constructed in the Dinwoody Formation approximately in the center of the Middle Henry immediately adjacent to the location where waste rock overlies the formation. The fall 2007 selenium concentration in this well was 0.017 mg/l. Given the postulated flow direction to the northwest along strike, well MMW022 should provide a reasonable measure of impacts on ground water within the Dinwoody Formation from the southern portion of the mine. The direct push program planned for 2008 can provide information on possible ground-water discharge from the Dinwoody Formation into the alluvium along the mapped outcrop of the Henry thrust fault. Ground-water within the Dinwoody Formation likely flows northwestward along strike with possible discharge into the alluvium or basalt near the Little Blackfoot River. A well constructed in the Dinwoody Formation near the Little Blackfoot River northwest of well MMW003 would serve to monitor this potential pathway. A well at this location would be relatively shallow and would provide useful data with respect to both hydraulic gradient and water quality.

Enoch Valley Mine Site

The Enoch Valley Mine is also geologically less complex than either the Ballard Mine or the Blackfoot Bridge site (see the MWH plan view map). The formations dip to the west-southwest; the Wells Formation outcrops northeast of the mine pits with the Dinwoody Formation outcropping southwest of the mine pits. The primary structural features in the area are the Enoch Valley fault which parallels the Phosphoria outcrop on the east-northeast side and the Henry thrust fault which is located southwest of the mine pits. From south to north, MWH cross sections L-L’, M-M’, A-A’ and K-K’ show the configuration of the consolidated rock formations approximately at right angle to the strike. Sections D-D’ and J-J’ are aligned approximately along strike at the southeastern end of the mine-impacted area.

The logical direction for ground-water flow in the Wells Formation at the Enoch Valley Mine is along the strike of the unit, either to the northwest or the southeast. Well MMW009 was installed in 2007 and completed in the Wells Formation at a location near the north end of the mine. The selenium concentration from the 2007 sampling event was very small (0.001 mg/l). The logical location to complete a second well in the Wells Formation is near the southeastern end of the mine, probably northeast of wells MMW007 and MMW008. Water-level and water-quality data from this well will allow determination of flow direction and ground-water quality in this unit.

The logical direction for ground-water flow in the Dinwoody Formation at the Enoch Valley Mine is along the strike of the unit, either to the northwest or the southeast. A small area of waste rock overlies the Dinwoody Formation at the northern end of the mine with a much larger area near the south end of the mine. Three wells have been completed along the top of the Dinwoody Formation near the southeastern end of the mine (MMW007, MMW008 and MMW013). There is need to understand water quality conditions and water-level elevations deeper within the Dinwoody Formation, particularly near the southeastern end of the mine. A new well completed deeper in the Dinwoody Formation near MMW013 with a second well with a similar deeper completion near wells MMW007 and MMW008 would provide the information. Data from these two new wells should be sufficient to an understanding of ground-water flow direction and ground-water quality in this unit.

Please contact me if you have any questions related to the information provided in this memorandum. Thank you.

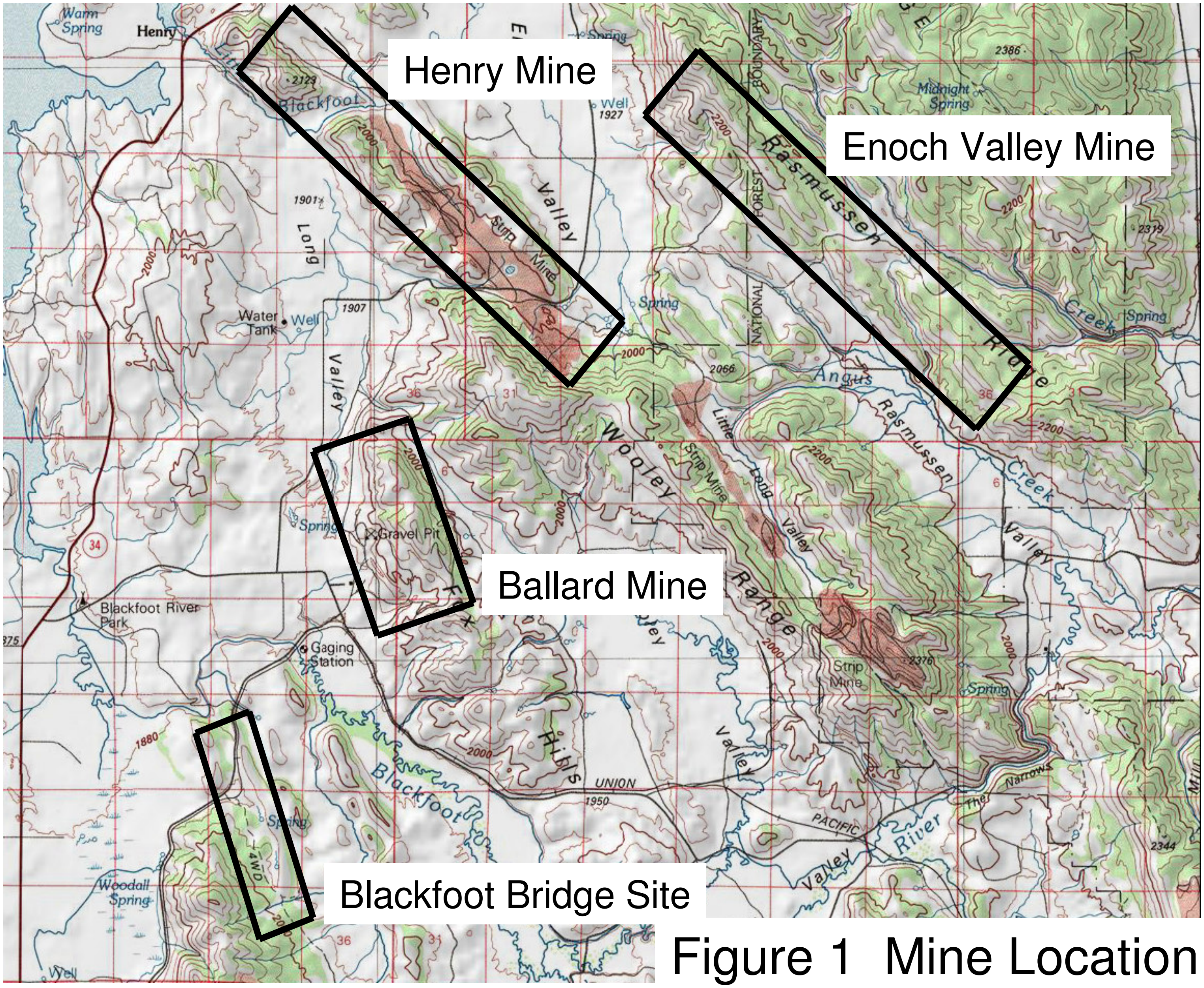

Figure 1 Mine Location Map

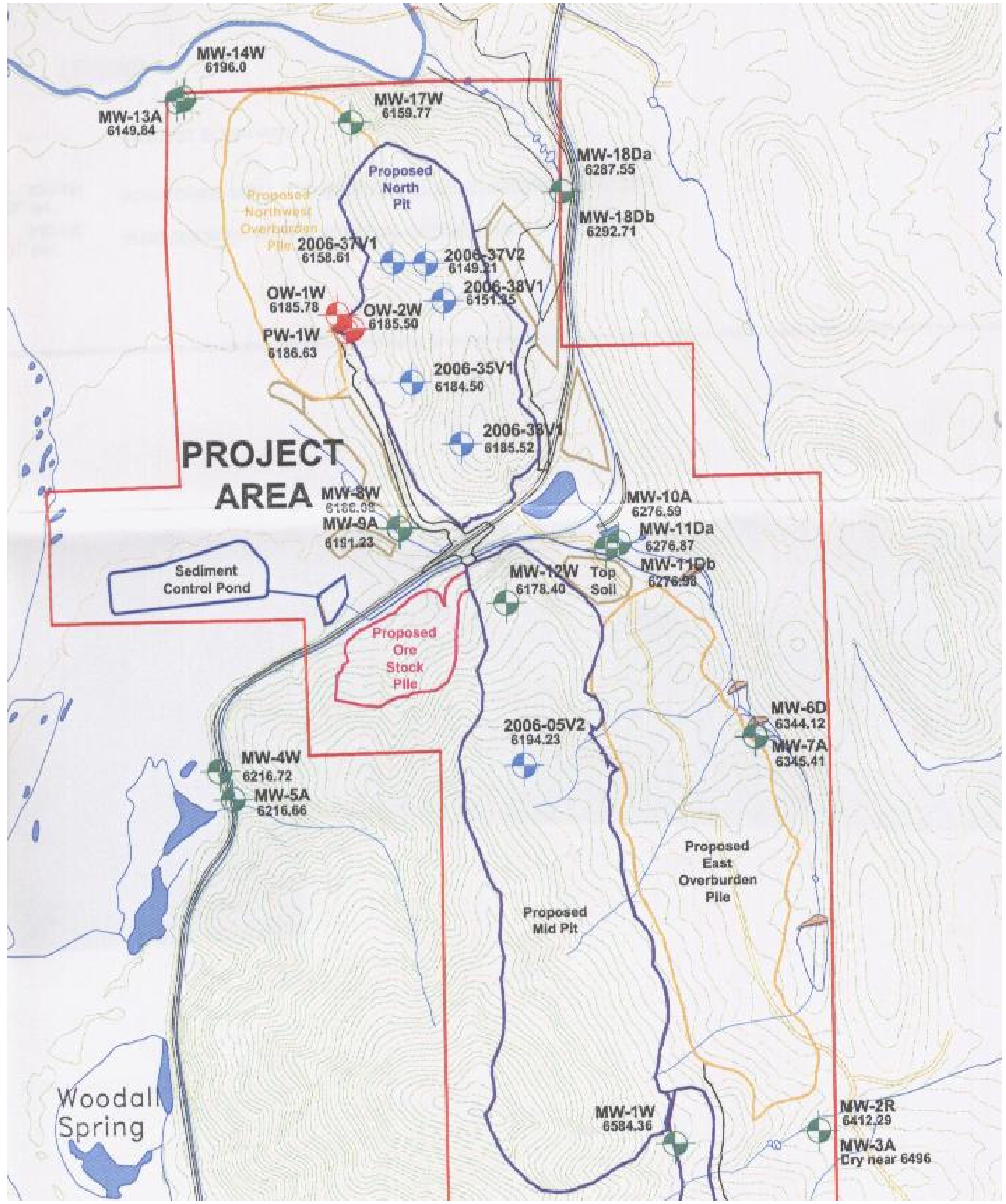

Figure 2 Location Map for Blackfoot Bridge Site Showing Ground-Water Elevations (feet)

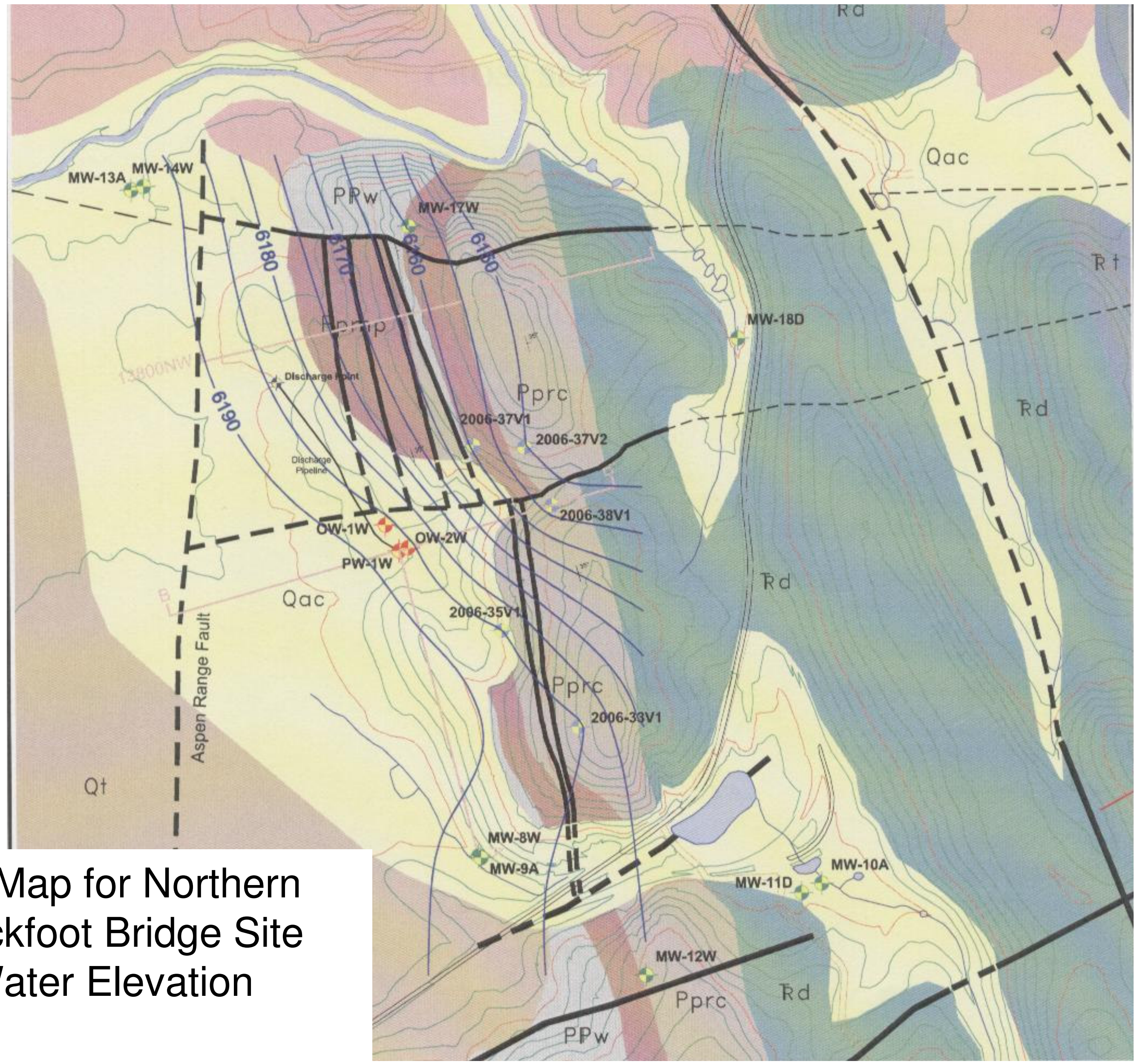

Figure 3 Geologic Map for Northern Portion of the Blackfoot Bridge Site Showing Ground-Water Elevation Contours (feet)

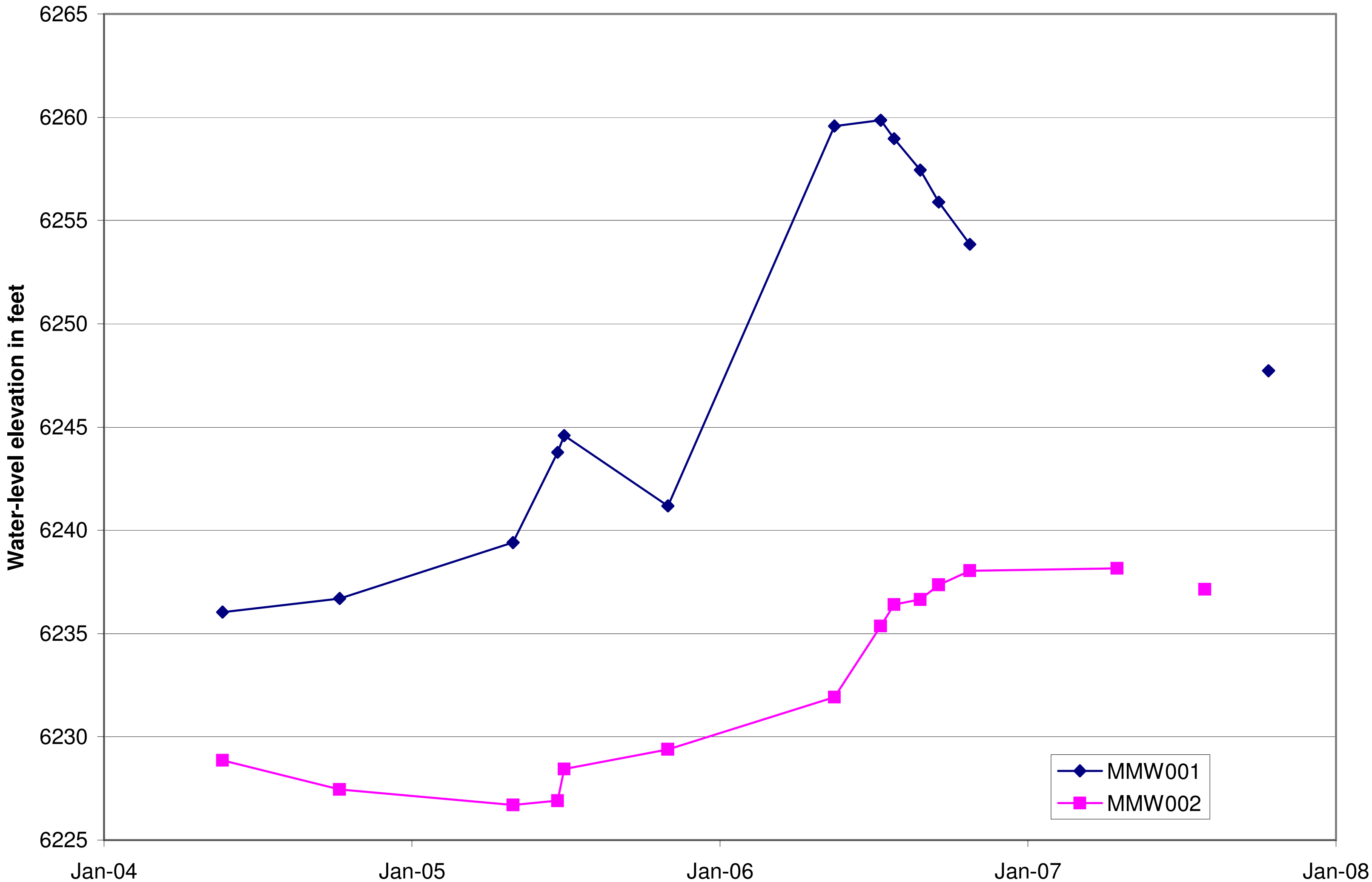

Figure 4 Hydrographs for Ballard Monitor Wells